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GEOTECTONICS OF THE ESTANCIA PLAINS

CHARLES R. KEYES

Prefatory.—The Estancia Plains lie in central New Mexico. They form the extreme northern portion of the vast Mexican tableland. In length they extend a distance of 150 miles; in width about 30 miles.

Previous to the year 1900 the Estancia Plains were regarded as the highest and driest bolson east of the continental divide. For this reason, if for no other, the underground-water possibilities of this region offered a theme for consideration that was of great interest. Large industrial interests made possible the investigations necessary to decipher the geological structure. Three new lines of railway were under construction across these plains and good water-supplies became a matter of prime import.

General features.—Geographically the Estancia Plains are located at the juncture of the four greatest physiographic provinces of our continent: The Great Plains, the Rocky Mountains, the Mexican tableland, and the Colorado plateau. There are within the borders of the Estancia area three very distinct types of orogenic structures. These are superimposed upon a general and very remarkable epeirogenic uprase.

At the north and east is the Rocky Mountain type, illustrating tremendous compressive action. Over the west and south the basin-range type of structure is finely shown in the immense tilted block mountains. In the west-central portion is the laccolithic type, represented by four distinct dome-shaped masses which have spread apart Cretacic strata.

In the main, the geologic structure of the Estancia Plains is that of a broad trough, but there are many interruptions and local deformations (Fig. 1). As compared with the structure of the Jornada del Muerto[1] farther south there is not nearly the regularity (compare with Fig. 2). As in the case of the latter plain the general aspect is that of a wide shallow valley which has a tendency to impart something of a synclinal character to the substructure. This apparent general relief feature, however, bears no relationship to the arrangement of the formations beneath. The surface of the plains is not a stratum-plane, as is naturally at first inferred, but a plane worn out in part at least on the beveled edges of the strata below, which lie at many different angles and dip in many different directions.

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[1] *Water Supply Paper No. 123*, U. S. Geological Survey, 1904.

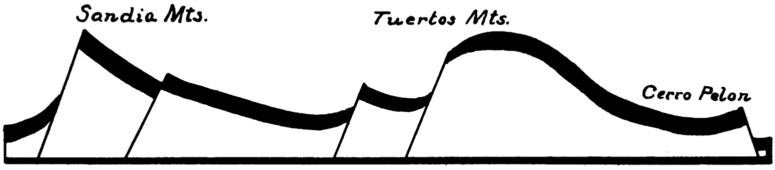

FIG. 1.—General structure of Estancia Plains.

This general structure of the plains appears to have been the characteristic feature of the region before their continuity was interrupted by the faulting which gave rise to the block mountains, and by the laccolithic intrusions.

In most of the parallel bolsons and valleys which are found in the high tableland region of New Mexico the bounding mountain blocks are so tilted that across some plains great fault-scarps face each other, as in the case of the Jarilla bolson immediately south of the Estancia district. Here the abrupt fault-scarp of the Sierra San Andreas, rising over 3,000 feet above the level of the plains, faces the equally abrupt scarp of the Sacramento Range to the east which rises even higher. In other instances, as in the Jornada to the southwest of the Estancia Plains, the main portion of the bolson is flanked on either side by the gentle backslopes of the monoclinal blocks. The fundamental plan of geologic structure is best indicated by diagram

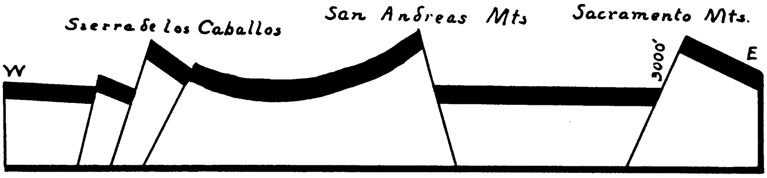

FIG. 2.—Structure of the basin ranges in central New Mexico.

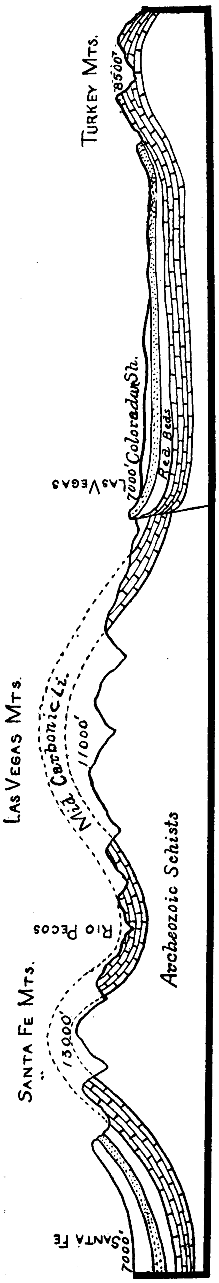

FIG. 3.—Geologic cross-section of the southern Rocky Mountains.

(Fig. 2). A similar arrangement representing the structure of the Estancia Plains is shown in Fig. 1.

The important factor to be taken into account in this region is the fact that the local geologic structure is not nearly so simple as it may at first glance appear. Everywhere there is greater or less complication. The great backslopes of the tilted mountain blocks, instead of being continuous stratum-planes, are found to be faulted at frequent intervals; and the dips of the rocks change within very short distances.

Rocky Mountain type of structure.—The compressive type of mountain structure finds expression in the Estancia Plains region only in the extreme northeastern part, where the Rocky Mountains end by plunging downward beneath the plains surface. Only a single southward-pitching arch is represented within the limits of the district under consideration. Farther to the eastward the details of structure are more complete. The cross-section to the plains of Las Vegas beyond is well worth much more consideration than can be given it here (Fig. 3).

There is abundant evidence of marked compressive action within the plains area here described, the geologic date of which is probably somewhat earlier than that which the southern nose of the Rockies represents. This period of compression was Early Cretacic. While the evidences are very clear within the limits of the Estancia region there are more abundant exemplifications a short distance outside of this area. On the

Chupadera Mesa just south of Estancia there is an unusually good exposure bearing directly upon this fact (Fig. 5). In some other examples the geologic dates of the compressure are not so clearly set off. In the Sierra de los Caballos where a thrust-plane is shown to advantage (Fig. 4), the movement may have been very recent.

Basin-range type of mountain structure.—In marked contradistinction to the type just described the basin ranges are the result of faulting on an enormous scale. The mountain blocks, rising 3,000 to 5,000 feet above the general level of the high plains which itself is 6,000 feet above the sea, appear tilted as ice cakes in a stream.

There are several instructive features relating to the structure of the Desert ranges that are shown better in and about the region under consideration than anywhere else in the Southwest. Recently a new interest has been awakened in the tectonics of the Great Basin by the publication of a number of more or less suggestive articles. The main structural features about which discussion centers appear to be whether the basin ranges are the result of normal faulting and form "block mountains;" or whether the "block" aspect is only apparent, the monoclinal "blocks" originally being, in reality, sharp asymmetric folds in which subsequent erosion has worn off the steeper limb faster than the other.

In the elucidation of the arguments by specific example, it is unfortunate that many of the illustrations selected have not been chosen with greater discernment. It is now well understood that some of the instances noted furnish the most conclusive proofs directly contrary to the purposes for which they were cited. Without entering into details in regard to many of these cited examples from other parts of the Great Basin region it seems pertinent at this time to call attention briefly to certain features displayed in the New Mexican part of the field. These may help to explain similar phenomena in other districts.

As has recently been noted, the geologic sequence in central New Mexico is especially noteworthy on account of the almost complete absence of the Paleozoic rocks and the enormous development of Mesozoic strata. The important member of the sequence above the Azoic metamorphics is the Mid Carbonic limestone which attains a normal thickness of over 2,000 feet.

No evidence has yet been found that would indicate that any of the present mountain blocks were produced by folding. All observations go to show on the other hand that only faulting is involved. To be sure the sedimentaries of some of these mountains are often folded and closely corrugated. Thrust-planes are plainly visible. Numerous other indications point to tremendous compression at some time or other. But the period of this compression has been found to be mainly a very different one from that during which the present mountains were formed. The compressive action was exerted long before the existing mountain blocks began to rear their heads above the vast plains. Chronologically this period of compressive conditions was manifestly subsequent to the Carbonic period because the rocks of this age are involved; but it was before the Late Cretacic period, since Cretacic strata are as clearly not affected.

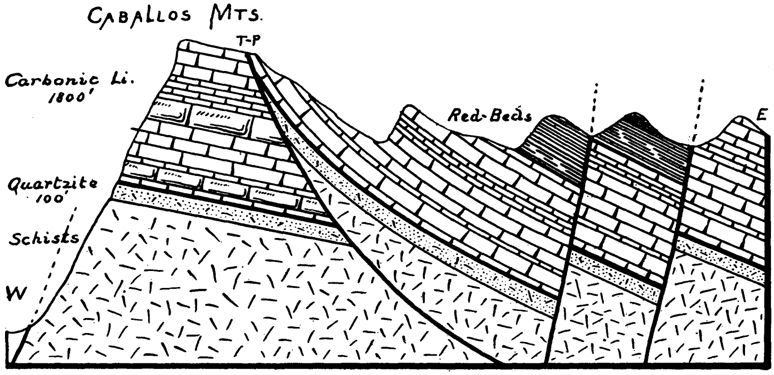

FIG. 4.—Old and modern faulting in Caballos Mountains.

Certain thrust-planes displayed in the Sierra de los Caballos, to the south of the Estancia region, the geologic sections of which have a bearing upon this point are particularly instructive while the production of others is thought to be somewhat later. Near the highest point of the range, known as Timber Peak, the fault-scarp is over 3,000 feet high and displays an excellent exposure of the rocks throughout this entire vertical distance. The transverse section of the mountain ridge, as shown a short distance to the north, is represented in diagram (Fig. 4). The heavy line, *T–P*, indicates the position of an exceedingly well-displayed thrust-plane. Along it the beds are very much contorted. The inclination of this thrust-plane is now rather steep, but this is due partly to the fact that the present position of this structure is not the original one. Since the time of its formation the thrust-plane also has been tilted to a marked degree. In point of time the formation of the thrust-plane long antedates the uprising of the present mountain block.

There are in the Sierra de los Caballos at least three distinct periods of faulting. The first was before the formation of the present mountain ridge; the second was coeval with its formation; and the third was long subsequent to its uprising.

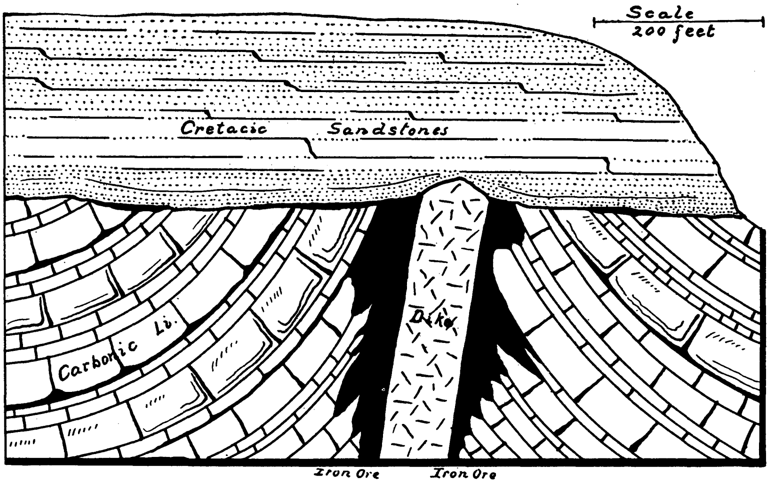

FIG. 5.—Unconformity of Cretaceous on Carboniferous, near Dios Springs.

Were it not for the exceptionally clear evidence to the contrary, casual examination could very easily lead to the conclusion that the Caballos mountain range had been produced by sharp folding, and that the crest of the asymmetric fold had been removed through erosion. The deduction is a natural one especially when in a view from the summit of the range there are plainly shown the strata dipping eastward to form a broad syncline, and coming up again with westerly dips in the great San Andreas block, 30 miles away.

It so happens that in the region under consideration the general sequence of geologic events is sufficiently well known to us to give a good insight into some of the actual conditions that have existed.[1]

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[1] *American Journal of Science* (4), Vol. XVIII, pp. 356–58, 1904.

A number of observations lately made emphasizes the great importance of the unconformity at the base of the Cretacic strata of the region. For example, in the Chupadera Mesa in eastern Socorro County, there are found Carbonic limestones highly inclined on either side of huge trachyte dikes, over the whole of which recline nearly horizontally the Cretacic sandstones (Fig. 5). This surface of unconformity represents extensive land erosion. During the interval for which it stands the strata of the region were folded and planed off long before the later Cretacic sediments were laid down.

In nearly all of the basin ranges there are abundant evidences of marked compression producing the phenomena of folding. Yet in every instance personally observed the period of these movements is manifestly long prior to the elevation of the present mountains. The ancient tectonics of the basin ranges is a theme of very great interest.

There is another very deceptive feature connected with the formation of the blocklike mountains of some portions of the Mexican tableland. At the foot of the steeper slope the strata are often found to be tilted at a high angle and inclined away from the range. This attitude of the beds readily suggests at first the possibility of the mountain ridge's being a sharp anticline with the center completely removed through erosion, leaving the limbs of the arch unequally exposed. This condition might be easily fancied because of the fact that the greater part of the height of the mountains, 3,000 to 5,000 feet, is usually composed of massive crystallines and schists, while the crest and the backslope are of limestone.

There are many good reasons for believing that such phenomena as these instead of being ascribable to folding of the asymmetrical type are to be considered merely as an accompaniment of normal faulting. The displacement, however, is on a gigantic scale and under conditions not usually met with. When the hade is not vertical, or nearly so, the strata on the down-throw side to a greater or less degree lag, until a considerable zone is produced in which the beds become highly inclined and in many cases stand even nearly perpendicular. A typical instance is the Sandia Range, east of Albuquerque, as represented below (Fig. 6).

There are strong theoretical grounds for thinking that faulting instead of folding is to be invoked to explain the structure of the so-called block mountains of the Great Basin region. The principle was clearly set forth by Le Conte[1] as long ago as 1889, when discussing the district between the Sierra Nevada and the Wasatch Mountains. As considered in his textbook[2] the same author has regarded the area in question as a region which was subjected to slow and general uprising but continually adjusted itself through normal faulting in great blocks. By the tilting of these blocks mountain ranges were produced on the elevated edge while on the depressed side were formed valleys which were subsequently filled with sediments. Lauterback[3] is inclined to modify this view somewhat by regarding the mountain block and the valley block as distinct.

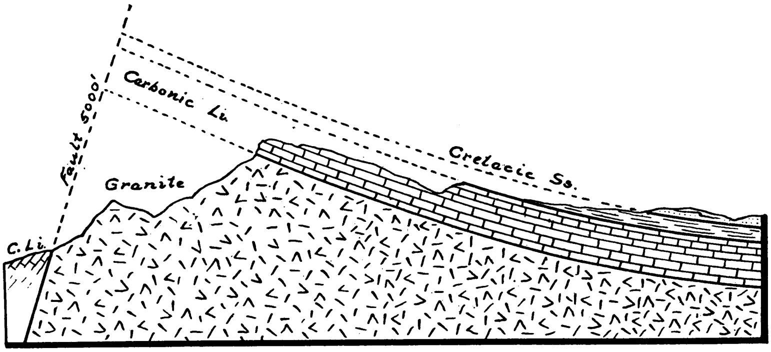

FIG. 6.—Fault-scarp of the Sandia Mountains.

The present relief features of the region are, however, mainly the product of general desert leveling, that is the result of eolian erosian under conditions of an arid climate, and the mountains are to be looked upon as remnantal ranges which are essentially monadnocks.

Laccolithic type of mountain structure.—In the northwestern part of the Estancia Plains there rise four isolated groups of lofty peaks. The several groups are five to six miles from one another and lie in a straight line trending nearly in a northeast and southwest direction. The southernmost group is known as the San Ysidro, or South

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[1] *American Journal of Science* (3), Vol. XXXVIII, p. 259, 1889.

[2] *Elements of Geology*, 5th ed., p. 242, 1904.

[3] *Bulletin of the Geological Society of America*, Vol. XV, p. 343, 1904.

Mountains; then comes the Tuertos group; next, the Ortiz, Placer, or Gold mountains; and then, at the north, the Cerillos Hills.

At the present time each of these mountain groups is a huge, many-peaked boss of augitic and hornblendic andesite. Each also rises out of the Cretacic sandstones which are upturned all around. In some places great intrusive sheets extend out from the central mass to a distance of a dozen miles or more; and immense dikes radiate often to twice the distance named.

All evidence goes to show that each of the mountain groups is a laccolith. The molten material, forced upward from beneath, instead of reaching sky floated the overlying strata, forming enormous domes, the tops of which were subsequently removed through erosion. A cross-section of the Ortiz group indicates the structure as represented in Fig. 7.

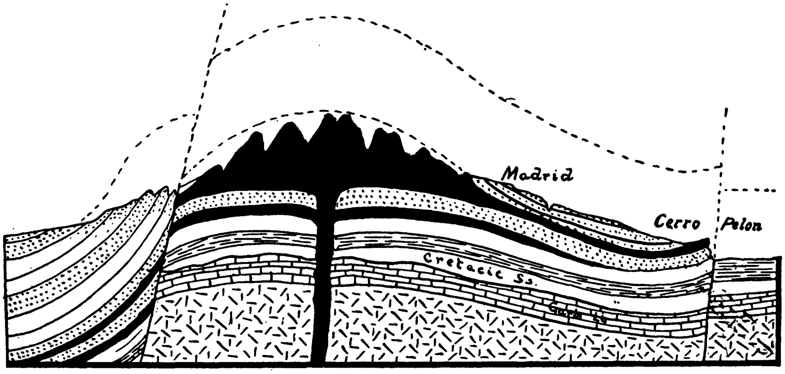

FIG. 7.—Structure of the Ortiz laccolith.

The Ortiz group displays to best advantage the various phenomena of laccolithic nature. The Carbonic limestones have been completely changed by heat into garnet rock, as is well shown at the Lucas mine on the south side of the great dome. Many dikes and several sills have the Ortiz mass as a center. The largest sill extends southeastward to the Cerro Pelon, a distance of about twelve miles. This sill is more than 200 feet thick. The great intrusive sheet is of special interest in the present connection for reason of its penetrating the Cretacic coal measures. There are several important coal seams in close proximity to the intrusive sheet. Where the sill has come directly into contact with the coal seam the latter has been entirely destroyed. When separated by a few feet of shale a fine grade of anthracite is produced. This variety of coal is extensively mined at the town of Madrid and elsewhere in the vicinity. Seams still farther removed from the sill are bituminous in character; while at a distance of 100 to 200 feet the coal seams are lignitic.

The relations of the sill to the coal seams suggest that the intrusive sheet itself may have followed along a large coal seam, perhaps the most extensive of all, as a horizon along which it was able to move most easily. Similar phenomena have been observed in the Scottish coal fields and in the coal fields of Germany and Hungary.

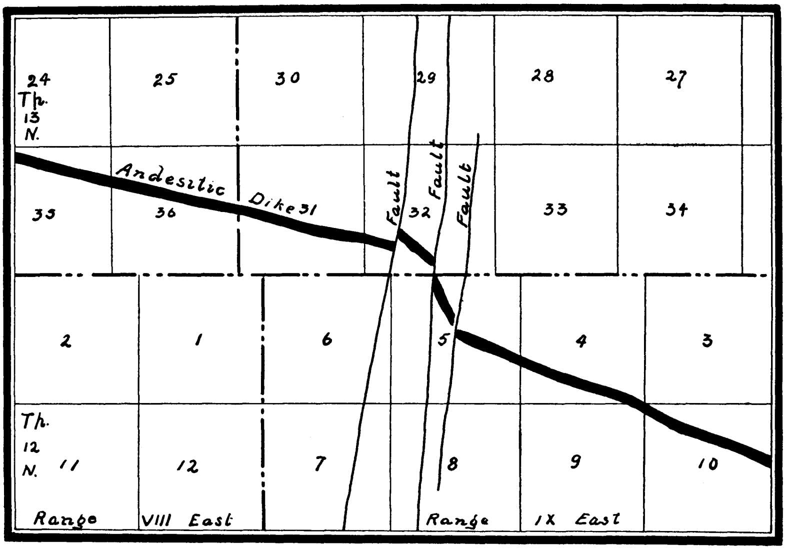

FIG. 8.—Plan of large dike cutting coal-field near Cerro Pelon.

The dikes originating from the Ortiz mass often extend a score of miles across the plains as huge walls rising 100 to 200 feet above level surface. Some of these dikes show the amount of lateral displacement of the faults. One dike in particular has suffered movement in a remarkable way, as shown in the groundplan (Fig. 8). The squares in the cut are one mile in each direction.

Relations of the structure to the plains surface.—The even surface of the Estancia plains, vast as it is, is not, according to the strict physiographic usage of the term, that of a structural, or stratum-plane, valley. While in general the rocks are only gently deformed they are locally sharply folded, highly inclined, or even standing on edge. As has been recently shown[1] bolson plains, of which the Estancia Plains are a type, have not the simple substructure that is commonly ascribed to them. They do not appear to be necessarily any newer or later than the plateau plains which overlook them. Their constructional detrital covering is no more important than that of the plateau plains. The wash-deposits brought down from the mountainous periphery are relatively of small importance.

On the other hand, it has been clearly demonstrated in a number of cases that the bedrock surface of the bolson plains, or that plane beneath the detrital covering, is a planation-surface worn out on the beveled edges of the indurated sedimentaries. This feature is particularly well displayed in the plains between the Ortiz and Sandia mountains. At the Uña de Gato, near Hagan, the structure is as represented below (Fig. 9). The dotted line represents the plains surface; it extends to the right a distance of 20 miles.

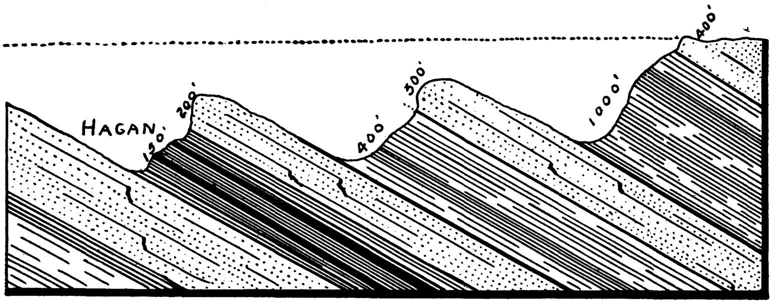

FIG. 9.—Alternation of Cretaceous shales and sandstones at Hagen, thickness about 4,000 feet.

The character of this beveling of highly inclined beds, in this case Cretacic sandstones, is admirably shown in the accompanying view near Los Cerrillos, from a photograph taken by Dr. D. W. Johnson. The horizontal beds at the top and above the old planed surface are composed of volcanic breccias, which in turn are overlain by late mesa clays and sands. (See Fig. 12.)

Characteristic rock-masses.—There are represented in the Estancia region five principal kinds of rock-masses. In the great fault-scarp on the west face of the Sandia Mountains there are shown about 4,000 feet of schists, highly metamorphosed clastics, and old intruded granites. These are without much doubt Azoic in age.

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[1] *American Journal of Science* (4), Vol. XV, p. 207, 1903.

Following the fundamental complex are blue limestones of great thickness. They are Mid-Carbonic in age. Above the limestones is normally a remarkable succession of red-beds consisting of shales and shaly sandstones which are doubtless, in great part at least, also of Mid-Carbonic age.

Then comes a prodigious mass of yellow sandstones and shales belonging to the Mid- and Late Cretacic Ages. Finally, are the surface loams, sands and gravels of variable thickness, of Tertiary and Quaternary ages.

Besides the five general classes of rock-masses referred to there is a varietv of igneous types.

Geologic formations represented.—The general lithologic character, thickness, and stratigraphic relationships of the various geologic formations which are represented within the limits of the Estancia Plains area need not be described in detail at this time. Two terranal features should, however, be noted: The presence, in this region, of a great succession of "red-beds" fully 1,000 feet in thickness which is not the correlative homologe of the Kansas red-beds; and the remarkable sandstone forming the base of the Cretacic section of the region and to which the term Dakota sandstone has been long applied.

The red-beds of the Sandia side of the Estancia Plains have been termed the Bernalillo shales[1] and they represent the uppermost and third member of the Maderan series.[2] The fact that these "red-beds" are neither of Permian nor of Jura-Trias Age was first made known in 1900 by Herrick[3] who discovered in them a large and characteristic fauna, that clearly connected the section with the so-called Permo-Carboniferous section of central Kansas. The Kansas red-beds or Cimarronian series, and the Triassic red-beds have been shown to be entirely absent in central New Mexico.[4] The title Manzano formation which has been used for the beds in question is inapplicable.

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[1] *Ores and Minerals*, Vol. XII, p. 48; also *Report of the Governor of New Mexico to Secretary of the Interior, for 1903*, p. 339, 1903.

[2] This *Journal*, Vol. XIV, p. 152, 1906.

[3] This *Journal*, Vol. VIII, p. 116, 1900.

[4] *American Journal of Science* (4), Vol. XX, p. 423, 1905.

To the eastward of the Estancia Plains there are three important "red-beds" formations, each nearly 1,000 feet thick, and superposed upon one another. They are of widely different geologic ages, and are separated by great erosional unconformities. One is of Mid-Carbonic Age, another of Late Carbonic Age, and the third of Triassic Age. Besides these red-beds there have been long recognized in the region other great red-colored terranes, in the Cretacic section, in the Tertiary section, and in the Devonic section.

At the base of the Cretacic section of this region the Rio Mora sandstone is an important member. It is the so-called Dakota formation of the early geologic reports of the Southwestern United States.

Unconformities.—All of the serial formations of New Mexico, as well as many of their minor members, are separated by marked planes of unconformity. Some of these indicate only notable oscillations of the old shorelines; but several of them are manifestly ancient erosion surfaces. Of the latter class may be mentioned the intervals represented by the sedimentation discordance between the Huronic crystallines and the Manzanan series, between the Cimmaronian and the Maderan, between the former and the Triassic, between the Triassic and the Cretacic, and between the last mentioned and the Cenozoic deposits.

In the interval between the top of the fundamental complex and the Manzanan limestones, there are missing all of the Cambric, the Ordovicic, the Siluric, the Devonic, and the Early Carbonic sequences. These are all very fully represented in the southern part of New Mexico. The interval between the Maderan series and the Cimmaronian shales and sandstones is occupied, a hundred miles south of the Estancia region, by about 3,500 feet of limestones and sandstones, known as the Guadalupan series and regarded as representing the true Permian of Russia. The great sequence of "red-beds," so long of uncertain geologic age, has thus lately been found to be partly of Mid-Carbonic, partly of Late Carbonic, and partly of Triassic Age; the three parts being separated by marked unconformities. A marked erosion unconformity also separates the Triassic shales from the Mid-Cretacic sandstones of the so-called Dakotan series. The missing terranes, represented by the Morrison beds of Jurassic Age and the

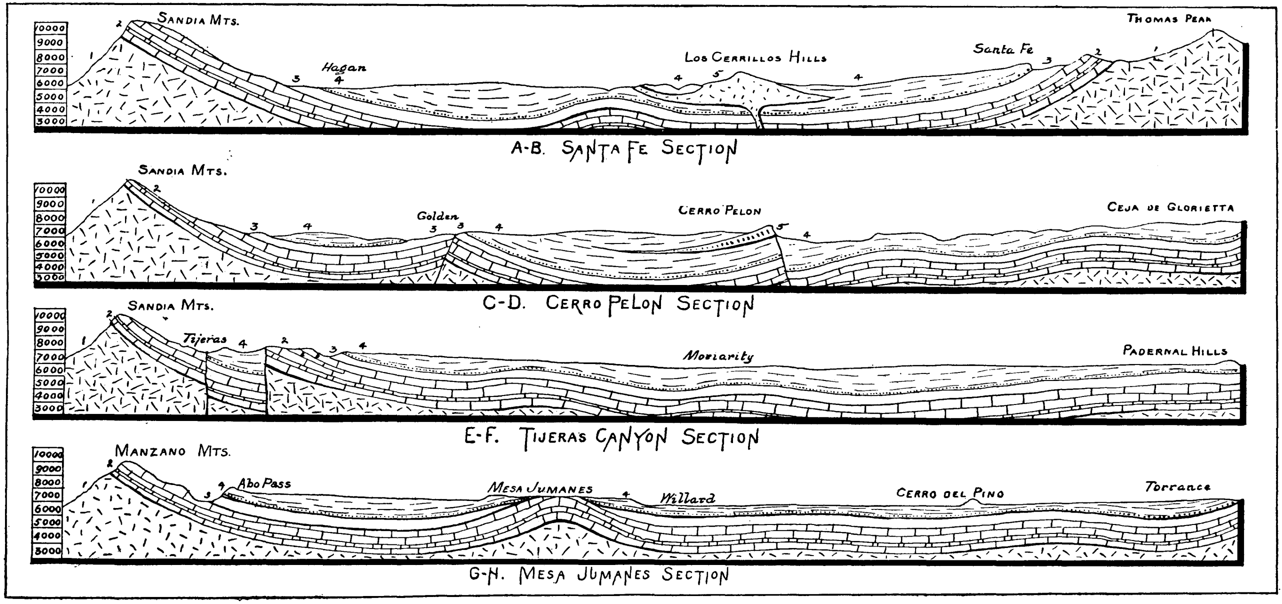

FIG. 10.—Geologic cross-sections of the Estancia Plains.

Comanche beds of Early Cretacic Age are both well displayed farther to the eastward near the Texas line.

General structural features.—The broader tectonic features of the region, as shown in the geologic cross-sections, offer some suggestive considerations regarding the forces which have been at work at the southern extremity of the Rocky Mountains. There are four cross-sections within the limits of the Estancia Plains that are particularly instructive. They may be called the northern section, the Cerro Pelon section, the typical plains section, and the southern section.

The northern, or Santa Fé, geologic cross-section extends from the Thomas Peak of the southern Rockies and a few miles southeast of the city of Santa Fé, in a southwesterly direction, to the Sandia Peak. The distance is 50 miles (section *A–B* of Group, Fig. 10). This section passes through the laccolithic dome of the Cerrillos Hills. In the main, the synclinal character is preserved between the Rocky Mountains and the Sandia Range. The blue Carbonic limestones are well displayed near both ends of the section. In the middle, a little to the south of the line of section, the limestones are also brought to the surface. All of the central part of the trough is occupied by Cretacic formations which are made up chiefly of sandstones.

The Cerro Pelon section trends nearly east and west (section *C–D*). The section is marked by two very pronounced faults which subdivide it into three nearly equal segments. The central portion owes its irregularities largely to the laccolithic disturbances of the neighborhood, the Ortiz group being on one side and the Tuertos group on the other. At the west end the section is monoclinal in character, there being very little if any rising of strata before the first fault is reached. Within this segment a short distance north of the section line several deep-drill wells have been put down.

The middle segment contains the Cerro Pelon, a sharp shoulder which is a feature of the landscape for a distance of many miles around. This hill rises 600 feet above the plain to the east. On its eastern face is a fault-scarp. The prominence of the elevation is due chiefly to the fact that it is capped by a plate of hornblendic andesite which has a thickness of over 400 feet. This capping-plate dips to the westward and is soon covered by the yellow sandstones of the Cretacic Age. The andesitic plate is in reality a great sill, from the Ortiz laccolith, 12 miles to the westward, now bent into a broad syncline.

Some distance beneath the andesitic plate which crowns the Cerro Pelon dark clay-shales are exposed. The valley plain to the eastward is also occupied by soft black shales. At a point several hundred feet below the foot of the Pelon hill a core drill penetrated these shales to a distance of 800 feet without passing through them. They are therefore over 1,000 feet thick.

The dark shales dip to the westward—the valley plain being worn out on their beveled edges. Six miles to the east of the Cerro Pelon the bottom of the shale formation reaches the surface and then the underlying sandstones continue as the surface rocks to the edge of the Glorietta escarpment, forming the western cliff of the Rio Pecos.

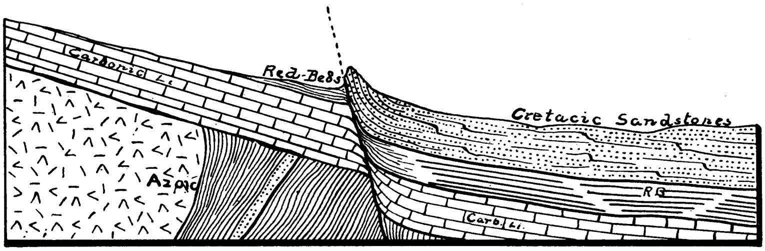

FIG. 11.—Fault bisecting the Sandia and Manzano ranges: displacement about 1,000 feet.

This eastern segment of the section is arching and is the pitching anticline by which the Rocky Mountains are terminated southward.

The Tijeras, or typical plains cross-section extends from the south end of the Sandia Range, at the upper end of the Tijeras Canyon, southeastwardly for a distance of 50 miles to the Padernal Hills, which form the drainage divide between the Estancia Plains and the Valley of the Pecos River (section *E–F* of Group, Fig. 10).

The most characteristic feature of this section is the even surface of the plains worn out on the beveled edges of the strata beneath. Only near the Sandia Range do the strata display any indications of marked dislocation. One of these faults has enabled the Tijeras Canyon to be formed between the Sandia and Manzano ranges. This fault (Fig. 11) has a throw of over 1,000 feet. At the hamlets of Tijeras and San Antonio it is well displayed. At the last-mentioned

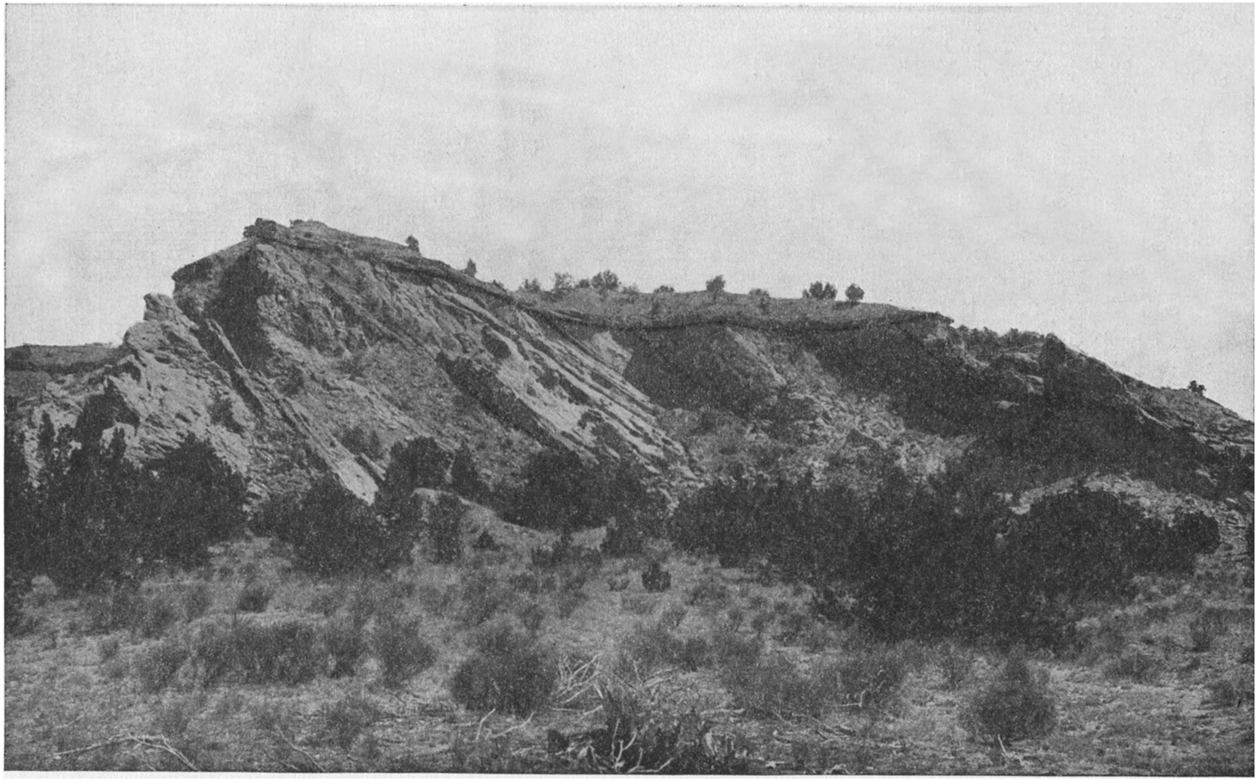

FIG. 12.—Tilted Cretaceous sandstones overlain by horizontal volcanic breccia, near Los Cerrillos, height 400 feet.

place the line of movement is marked by a long, high ridge formed of Cretacic sandstones standing on edge.

The southern, or Mesa Jumanes, cross-section passes eastward from the crest of the Manzano Mountains, over the northern extremity of the plateau plain known as the Mesa Jumanes, to beyond the Cerro del Pino near Torrance (section *G–H*, Group, Fig. 10). The western part of the section is synclinal in character with Cretacic beds as the surface rock. The Mesa Jumanes is a tableland with even surface which is elevated 300 feet above the level of the surrounding plains. Its sides are very steep. It appears to have an anticlinal structure, with Carbonic limestones forming the central part. The margins are composed of Cretacic sandstones. The explanation of this remarkable plateau plain appears to be found in the physiography of the region farther to the northeastward. It is believed that the Estancia Plains once formed a part of the Las Vegas plateau which extends northward to the Colorado line, and that the elevated Mesa Jumanes is a remnant of the Ocate plateau so conspicuous to the north of the city of Las Vegas.